10/591912
IAP12 Rec'd PCT/PTO 07 SEP 2006

The present invention relates to a tensionless leveller intended for levelling a metal strip and to the levelling method using said leveller.

A metal strip or plate undergoes various operations, such as hot rolling and cold rolling, which are intended to give it uniform dimensions over its entire length. Thus, in theory a rolled metal strip has at any point a constant thickness and a constant width.

However, the rolling operation is insufficient for obtaining a defect-free strip. This is because it exhibits non-developable flatness defects, such as waviness at the edges or the centre, and/or developable defects such as a curl or a crown, that is to say a curvature either along the length or along the width of the strip, respectively.

These flatness defects can be corrected by levelling the strip in a multi-roll leveller. Such a leveller consists of two superposed cassettes each supporting several motor-driven rolls, of constant diameter, offset with respect to one another and placed alternately above and below the path of the strip. This type of leveller is configured, in terms of the number of rolls, the diameter of the rolls, the centre-to-centre spacing and the setting, so as to achieve satisfactory levelling of the strip, the thickness of which lies within a defined range.

In a conventional leveller, the centre-to-centre spacings of the rolls are constant and set so that the ratio of the roll diameter to the centre-to-centre spacing is between about 0.90 and about 0.95. However, in this type of leveller, the levelling forces and moments are large. For the purpose of reducing them, manufacturers have developed levellers in which all of the centre-to-centre spacings are increased so that the ratio of the diameter to the centre-to-centre spacing is around 0.70 to 0.80. However, this no longer allows the non-developable defects to be corrected over the entire range of the leveller in terms of strip thickness, and in particular on a thinner strip.

Manufacturers have also proposed retracting some of the rolls, for example going from nine rolls to five. However, when the number of useful rolls is reduced, the degree of plastic deformation within the leveller varies abruptly, and it becomes difficult to bring the developable defects under control.

The object of the present invention is therefore to propose a leveller in which the levelling forces and moments are reduced compared with those of a

conventional leveller, while still maintaining good flatness correction over the entire range of the leveller, and by making it easier to bring curl and crown under control.

For this purpose, the subject of the invention is a tensionless leveller intended for levelling a metal strip, having an entry and an exit, comprising n+1 rolls, of the type comprising two superposed cassettes each supporting at least n/2 motorized rolls of constant radius R, offset with respect to one another and placed alternately above and below the path of the strip, the axis of each of the rolls of one cassette being separated from the axis of the immediately successive roll of the other cassette by a centre-to-centre spacing E_k, in which:

for k : 2 to 4, $R/E_k = R/E_1$;

for k : n-3 to n, $R/E_k = R/E_n$ and $R/E_n < R/E_1$; and

for k from 5 to n-1, $R/E_n \leq R/E_k \leq R/E_1$, and $R/E_k \leq R/E_{k+1}$,

said leveller optionally including means for adjusting the centre-to-centre spacings E_k.

The leveller according to the invention may furthermore have the following features:

- $n \geq 8$;
- when the thickness of the strip to be levelled is between 0.5 and 3 mm, $14 \leq n \leq 22$;
- when the thickness of the strip to be levelled is between 3 and 15 mm, $10 \leq n \leq 16$;
- for k from 1 to x, $0.90 \leq R/E_k \leq 0.95$, and for k from x+1 to n, $0.70 \leq R/E_k \leq 0.80$;
- for k from 1 to x, $0.90 \leq R/E_k \leq 0.95$, one of the centre-to-centre spacings E_x, where $5 \leq x \leq n-4$, being such that:

  $0.80 \leq R/E_x \leq 0.90$; and for k from x+1 to n, $0.70 \leq R/E_k \leq 0.80$; and
- for k from 1 to x, $0.90 \leq R/E_k \leq 0.95$, one of the centre-to centre spacings E_x, where $5 \leq x \leq n-4$, being such that :

  $0.80 \leq R/E_x \leq 0.90$, and $0.75 \leq R/E_{x+1} \leq 0.85$, and for k from x+2 to n, $0.70 \leq R/E_k \leq 0.80$.

The subject of the invention is also a method for levelling a metal strip, in particular a steel strip, in which this leveller is used with a degree of plastic deformation of at least 60% and at most 90%.

As will have been understood, the invention consists in proposing a leveller in which at least the first five rolls starting from the entry of the leveller have a radius/centre-to-centre spacing ratio identical to that of conventional levellers, in which at least the last five rolls from the entry of the leveller have a radius/centre-to-centre spacing ratio close to that of a decurler, and in which the centre-to-centre spacing between the intermediate rolls of the leveller is advantageously increased.

The features and advantages of the present invention will become more clearly apparent over the course of the following description, given by way of non-limiting example and with reference to the appended drawings in which:

– Figure 1 shows a schematic cross-sectional view of a tensionless multi-roll leveller according to the invention;

– Figure 2 shows a calculation curve of the residual curl of a levelled metal strip as a function of the exit clamping of the leveller, for a degree of plastic deformation of 60%; and

– Figure 3 shows a calculation curve of the residual curl of a levelled metal strip as a function of the exit clamping of the leveller, for a degree of plastic deformation of 80%.

Figure 1 shows schematically a leveller 1 comprising two superposed cassettes 2, 3, each supporting motorized rolls 4, 4' of constant radius R. To level a metal strip 5, this strip 5 is made to run between the rolls 4, 4' and a leveller entry, corresponding to the entry of the strip 5 into the leveller 1, and a leveller exit, corresponding to the exit of the strip 5 from the leveller 1, are thus defined. The rolls 4, 4' are positioned so as to be offset one with respect to another and placed alternately above and below the path of the metal strip 5. To obtain correct levelling of the strip 5, each cassette 2, 3 must support at least n/2 rolls 4, 4' and, more precisely, for a leveller 1 comprising n+1 rolls 4, 4', the lower cassette 2 comprises (n/2)+1 rolls 4 and the upper cassette 3 comprises n/2 rolls 4'. The axis of each of the rolls 4, 4' of a given cassette 2, 3 is separated from the

axis of the immediately successive roll 4, 4' of the other cassette by a centre-to-centre spacing E_k, which can be varied.

To obtain a levelled strip 5 with a zero curl, it is necessary to set the gap between the rolls 4 of the lower cassette 2 and the rolls 4' of the upper cassette 3 located on the exit side of the leveller 1, that is to say to set the entry clamping and exit clamping of the leveller 1. To adapt the setting according to the type of strip 5 to be levelled, the centre-to-centre spacing E_k may be varied using adjustment means (not shown).

The inventors have demonstrated by reducing the radius/centre-to-centre spacing ratio of the rolls down to a value of around 0.8, starting from the fifth roll from the entry of the leveller, in a leveller whose radius/centre-to-centre spacing ratio between at least the first five rolls from the entry of the leveller corresponds to the radius/centre-to-centre spacing ratio of a conventional leveller, the levelling forces and moments can be reduced by 5 to 25% depending on the type of adjustment made.

Thus, for the first five rolls from the entry of the leveller, that is to say when k varies from 2 to 4, the R/E_k ratio is equal to the ratio R/E_1, in which E_1 corresponds to the centre-to-centre spacing between the first roll from the entry of the leveller and the second roll from the entry of the leveller, R/E_1 being between 0.90 and 0.95, limits inclusive, which values correspond to the radius/centre-to-centre spacing ratio of a conventional leveller.

For the last five rolls from the entry of the leveller, that is to say when k varies from n-3 to n, the R/E_k ratio is equal to the ratio R/E_n, in which E_n corresponds to the centre-to-centre spacing between the last roll from the entry of the leveller and the penultimate roll from the entry of the leveller, R/En being between 0.70 and 0.80, limits inclusive, which values correspond to the radius/centre-to-centre spacing ratio of a conventional decurler.

Thus, in the leveller according to the invention, it is clear that the ratio R/E_1 is always greater than the ratio R/E_n. Furthermore, it is also recommended that, between the fifth roll from the entry and the (n-1)th roll from the entry of the leveller, that is to say when k varies from 5 to n-1, the following relationships are satisfied :

$$R/E_n \leq R/E_k \leq R/E_1, \text{ and } R/E_k \leq R/E_{k+1}.$$

These conditions make it possible to reduce the forces exerted on the rolls and to reduce the moment needed for levelling. Thus, for an equivalent results in terms of levelling, the power of the leveller according to the invention will be 15 to 20% less than the power of a conventional leveller.

Furthermore, the inventors have observed an increase in the number of operating points using a leveller according to the invention, compared with a conventional leveller having the same number of rolls. The number of operating points of a leveller is determined by the adjustment to be made to the leveller in order to obtain, on leaving the leveller, a strip having a zero curl and a zero crown. Thus, the larger the number of operating points for a given leveller, the lower the constraint as regards the adjustments. This therefore represents an additional advantage, since the time required to adjust the leveller according to the invention will be able to be reduced.

In order for the non-developable flatness defects of the strip to be properly corrected, it is essential for the R/E_k ratio to be equal to the R/E_1 ratio, to within the accuracy of setting the centre-to-centre spacing between the rolls, for at least the first five rolls from the entry of the leveller.

Preferably, the leveller comprises more than nine rolls, that is to say n is equal to or greater than 8, in order for both non-developable defects and developable defects to be properly corrected. This is because, with fewer than nine rolls, it becomes difficult to bring the developable defects under control, and the metal strip may retain a residual crown and a residual curl.

Advantageously, to make the adjustments easier and to properly correct all the flatness defects of a metal strip within a thickness range from 0.7 to 3 mm, the leveller comprises between 15 and 23 rolls (limits inclusive), i.e. $14 \leq n \leq 22$.

When the metal strip has a thickness range between 3 and 15 mm, the leveller advantageously comprises between 11 and 17 rolls, i.e. $10 \leq n \leq 16$.

Depending on the quality of resolution of the flatness defects and the desired reduction in levelling force and moment, the inventors have developed various types of leveller, which we will now describe.

According to a first embodiment of the invention, the leveller is divided into two zones. A first zone is thus between the first roll from the entry of the leveller and the (x+1)th roll from the entry of the leveller, that is to say when k varies from

1 to x, and extends at least as far as the fifth roll from the entry of the leveller. In this first zone, the radius/centre-to-centre spacing ratio R/E_k is constant and between 0.90 and 0.95 (limits inclusive). The second zone lies between the (x+1)th roll from the entry of the leveller and the last roll from the entry of the leveller, which is the (n+1)th roll, that is to say when k varies from x+1 to n, and starts at least from the (n-3)th roll from the entry of the leveller. In this zone, the radius/centre-to-centre spacing ratio R/E_k is constant and between 0.70 and 0.80 (limits inclusive).

According to a second embodiment of the invention, the leveller is divided into three zones. A first zone lies, as in the first embodiment, between the first roll from the entry of the leveller and the (x+1)th roll from the entry of the leveller, that is to say when k varies from 1 to x, and extends at least as far as the fifth roll from the entry of the leveller. In this zone, the radius/centre-to-centre spacing ratio R/E_k is constant and between 0.90 and 0.95 (limits inclusive). Next, a second zone in which one of the radius/centre-to-centre spacing ratios, which will be called R/E_x, is between 0.80 and 0.90 (limits inclusive). This second zone lies between the fifth roll from the entry of the leveller and the (n-4)th roll from the entry of the leveller, that is to say when x varies from 5 to n-4. Finally, a third zone lies between the (x+1)th roll from the entry and the last roll of the leveller (the (n+1)th roll), that is to say when k varies from x+1 to n. In this third zone, the radius/centre-to-centre spacing ratio R/E_k is constant and between 0.70 and 0.80 (limits inclusive).

In a third embodiment of the invention, the leveller is again divided into three zones. A first zone lies, as in the previous embodiments, between the first roll from the entry of the leveller and the (x+1)th roll from the entry of the leveller, that is to say when k varies from 1 to x, and extends at least as far as the fifth roll from the entry of the leveller. In this zone, the radius/centre-to-centre spacing ratio R/E_k is between 0.90 and 0.95 (limits inclusive). Next, a second zone in which one of the radius/centre-to-centre spacing ratios, which will be called R/E_x is between 0.80 and 0.90 (limits inclusive) and the radius/centre-to-centre spacing ratio R/E_{x+1} is between 0.75 and 0.85 (limits inclusive). This second zone lies between the fifth roll from the entry of the leveller and the (n-4)th roll from the entry of the leveller, that is to say when x varies from 5 to n-4. Finally, a third

zone lies between the (x+2)th roll from the entry of the leveller and the last roll of the leveller (the (n+1)th roll), that is to say when k varies from x+2 to n. In this third zone, the radius/centre-to-centre spacing ratio R/E_k is constant and between 0.70 and 0.80 (limits inclusive).

The invention also relates to a method for levelling a metal strip, in which one of the levellers described above is used with a degree of plastic deformation of at least 60% but at most 90%.

The degree of plastic deformation of a metal strip is defined as being the thickness of the plastically deformed metal strip to the total thickness.

Thus, if the degree of plastic deformation is less than 60%, it is no longer possible to remedy the flatness defects of the strip. However, if this degree of plastic deformation is greater than 90%, the metal strip becomes difficult to level and in this case it is also difficult to remedy the flatness defects of the strip.

The metal strip to be levelled may be made of steel, either carbon steel or stainless steel, coated with a metal coating, for example based on zinc, or with an organic coating.

The invention will now be illustrated by examples given by way of non-limiting indication.

A conventional leveller, denoted by leveller X, comprising (k+1) rolls with k equal to 16, i.e. seventeen rolls, with a diameter of 57 mm and a constant centre-to-centre spacing E_k of 30 mm (a leveller of the BRONX type), therefore having a constant radius/centre-to-centre spacing ratio R/E_k of 0.95, was modified in order to obtain various levellers according to the invention, namely:

Leveller A : for k from 1 to 4, $R/E_k = 0.95$ and
for k from 5 to 16, $R/E_k = 0,80$;

Leveller B : for k from 1 to 4, $R/E_k = 0.95$,
for k = 5, $R/E_k = 0.865$ and
for k from 6 to 16, $R/E_k = 0.80$; and

Leveller C : for k from 1 to 4, $R/E_k = 0.95$,
for k = 5, $R/E_k = 0.90$, and $R/E_{k+1} = 0.85$, and
for k from 7 to 16, $R/E_k = 0.80$.

A steel strip 2 mm in thickness and 1000 mm in width was then made to run through each of these levellers A, B, C and X, applying either a degree of

plastic deformation of 60% or 80%. The steel in question was a steel of the THR1000 type, the yield strength $R_{p0.2}$ of which was 900 MPa.

Figures 2 and 3 show a calculation curve of the residual curl of the levelled steel strip as a function of the exit clamping of the leveller for a degree of plastic deformation of 60% (Figure 2) and for a degree of plastic deformation of 80% (Figure 3).

The various levellers are identified by the following symbols:

- leveller A : symbol ■,
- leveller B : symbol ▲ ,
- leveller C : symbol **X**, and
- leveller X : symbol ◆.

Finally, the leveller entry forces, the leveller exit forces, the total forces and the moment of the leveller were measured for each leveller and for each degree of plastic deformation. The reductions obtained in each of the levellers A, B and C according to the invention compared with the conventional leveller X were calculated and all of the results are given in Tables 1 and 2.

Table 1: reduction in forces and moment, and increase in number of operating points, for a 60% degree of plastic deformation

	Force reduction at leveller entry (%)	Force reduction at leveller exit (%)	Total force reduction (%)	Total moment reduction of the leveller (%)	Number of operating points
Leveller A	23	11	17	35	1
Leveller B	18	14	15	31	3
Leveller C	15	14	14	25	9
Leveller X	-	-	-	-	6

Table 2: reduction in forces and moment, and increase in number of operating points, for a 80% degree of plastic deformation

	Force reduction at leveller entry (%)	Force reduction at leveller exit (%)	Total force reduction (%)	Total moment reduction of the leveller (%)	Number of operating points
Leveller A	23	8	16	27	5
Leveller B	17	11	14	24	5
Leveller C	15	13	14	22	5
Leveller X	-	-	-	-	4

It is apparent from these two tables of results that leveller A is the leveller allowing the largest reductions in force and moment to be obtained, irrespective of the degree of plastic deformation. However, as may be seen in Figures 2 and 3, this leveller is not necessarily the most reliable if it is desired to give the metal strip a perfectly zero curl, since, in particular when the degree of plastic deformation is 60%, the number of operating points is 1, whereas it is 9 in the case of leveller C.